MODULE 13
RADAR PRINCIPLES

OBJECTIVES

At the completion of this module, the student will be able to

1) Describe in general terms how weather radar operates
2) Illustrate how the WSR-88D acquires data
3) Identify the WSR-88D reflectivity and velocity products

INTRODUCTION

Once thunderstorms develop, the most effective electronic observation tool is radar. **Radar**, which stands for **RA**dio **D**etection **A**nd **R**anging, has been utilized to detect storms since the 1940's. Radar enhancements have enabled NWS staffs to examine storms with more precision. The NWS's newest radar is called the **WSR-88D**, which stands for **W**eather **S**urveillance **R**adar - 19**88 D**oppler (the prototype radar was built in 1988). As its name suggests, the WSR-88D is a Doppler radar, meaning it can detect motions toward or away from the radar as well as the location of precipitation areas.

DETECTION OF PRECIPITATION

Exactly how does radar work? As the radar antenna turns, it emits extremely short bursts of radio waves, called **pulses**. Each pulse lasts about .0000016 seconds, with a .00019-second "listening period" in between. The radio waves move out through the atmosphere at about the speed of light. The WSR-88D's pulses have an average transmitted power of about 450 kilowatts. If the radio waves strike a target, such as a raindrop, a hailstone, or an airplane, then a small portion of the energy (about a millionth of a millionth of a watt) is reflected back to the antenna.

By keeping track of the time it takes the radio waves to leave the antenna, hit the target, and return to the antenna, the radar can calculate the **distance** to the target. By recording the direction in which the antenna was pointed, the **direction** of the target is known as well. This information is calculated within the .00019-second listening period, and the process is repeated about 1,000 times per second. Generally, the better the target is at reflecting radio waves (i.e., more raindrops, larger hailstones, etc.), the stronger the reflected radio waves, or **echo**, will be.

Radar systems which only detect precipitation in this manner are referred to as **conventional radars**. Virtually all of the NWS radars which were in service before the WSR-88D were conventional units. As you may have concluded, conventional weather radar systems are complex machines, but the WSR-88D is even more sophisticated. Figure 13-1 below lists the primary components of the WSR-88D, and figure 13-2 shows the method of precipitation detection described above.

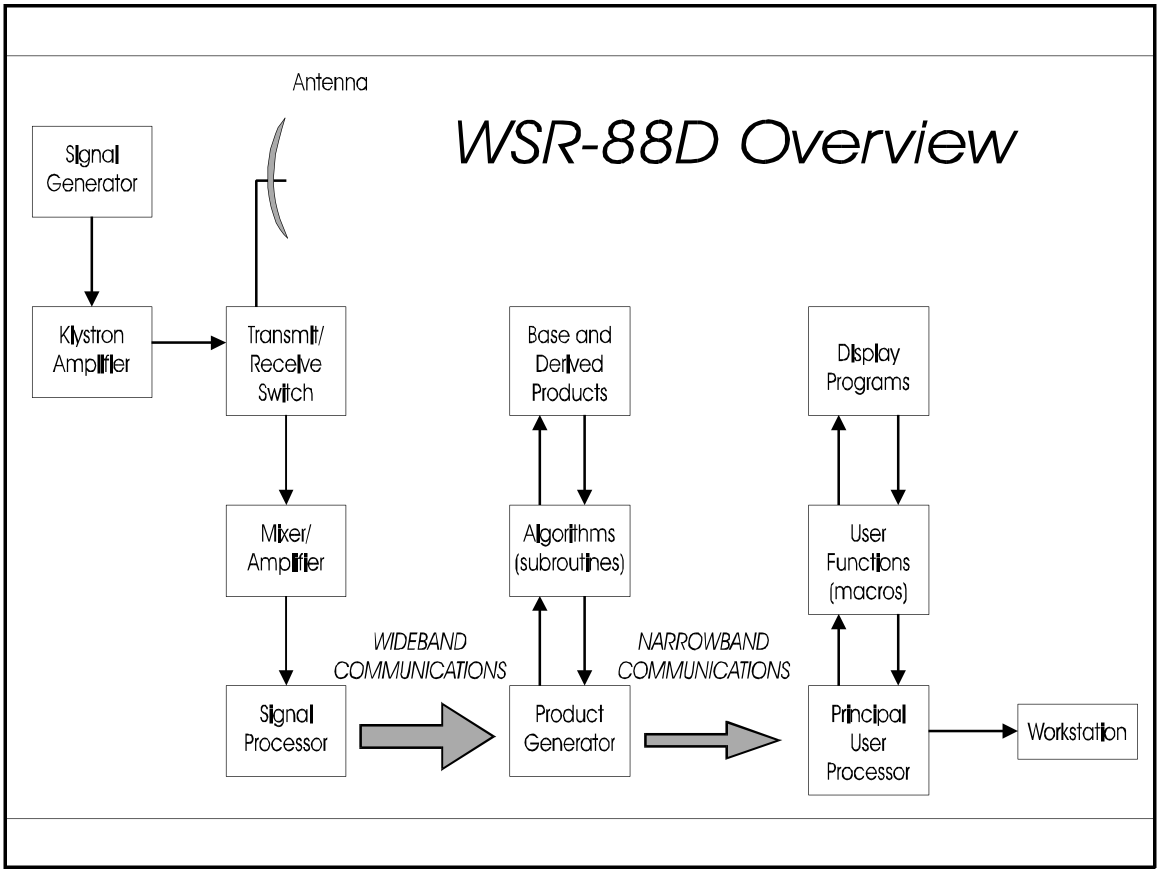

Figure 13-1: Block diagram of WSR-88D components and system operation

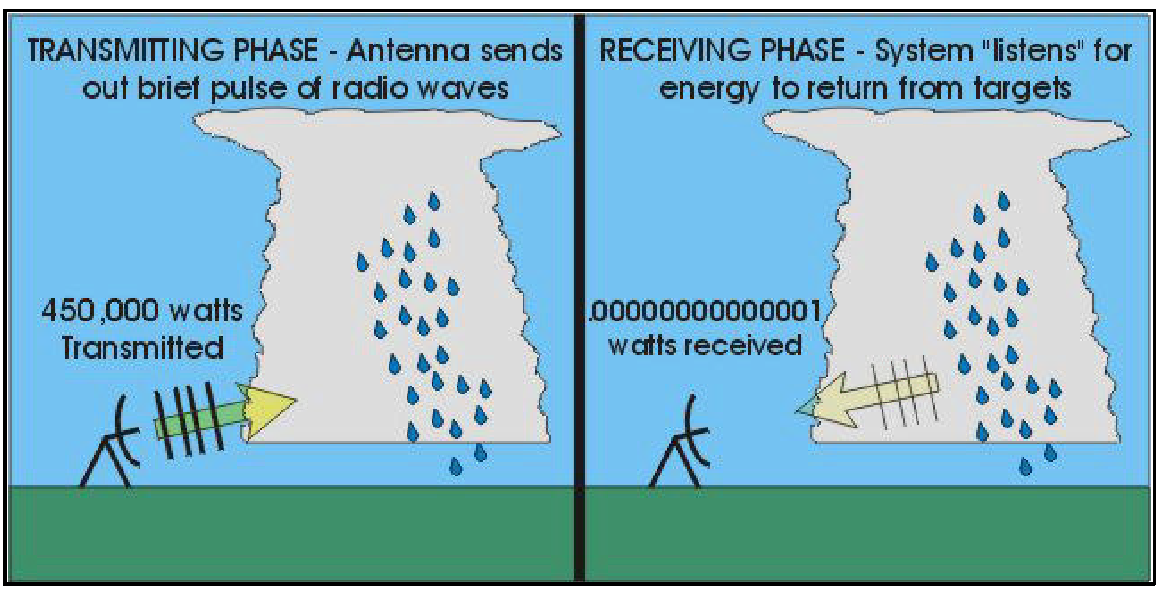

Figure 13-2: Transmitting and recceiving (listening) phases of weather surveillance radar

THE DOPPLER ADVANTAGE

Doppler radar systems such as the WSR-88D detect and locate precipitation in this same manner. However, Doppler systems also can provide information regarding the movement of targets as well. When the WSR-88D transmits a pulse of radio waves, the system keeps track of the **phase** (shape, position, and form) of the transmitted radio waves. By measuring the shift in phase between a transmitted pulse and a received echo, the target's **radial velocity** (the movement of the target toward or away from the radar) can be calculated as well. Generally, a positive phase shift implies motion toward the radar and a negative shift suggests motion away from the radar. The larger the amount of phase shift, the higher the target's speed. See Figure 13-3 for an example of Doppler velocity detection.

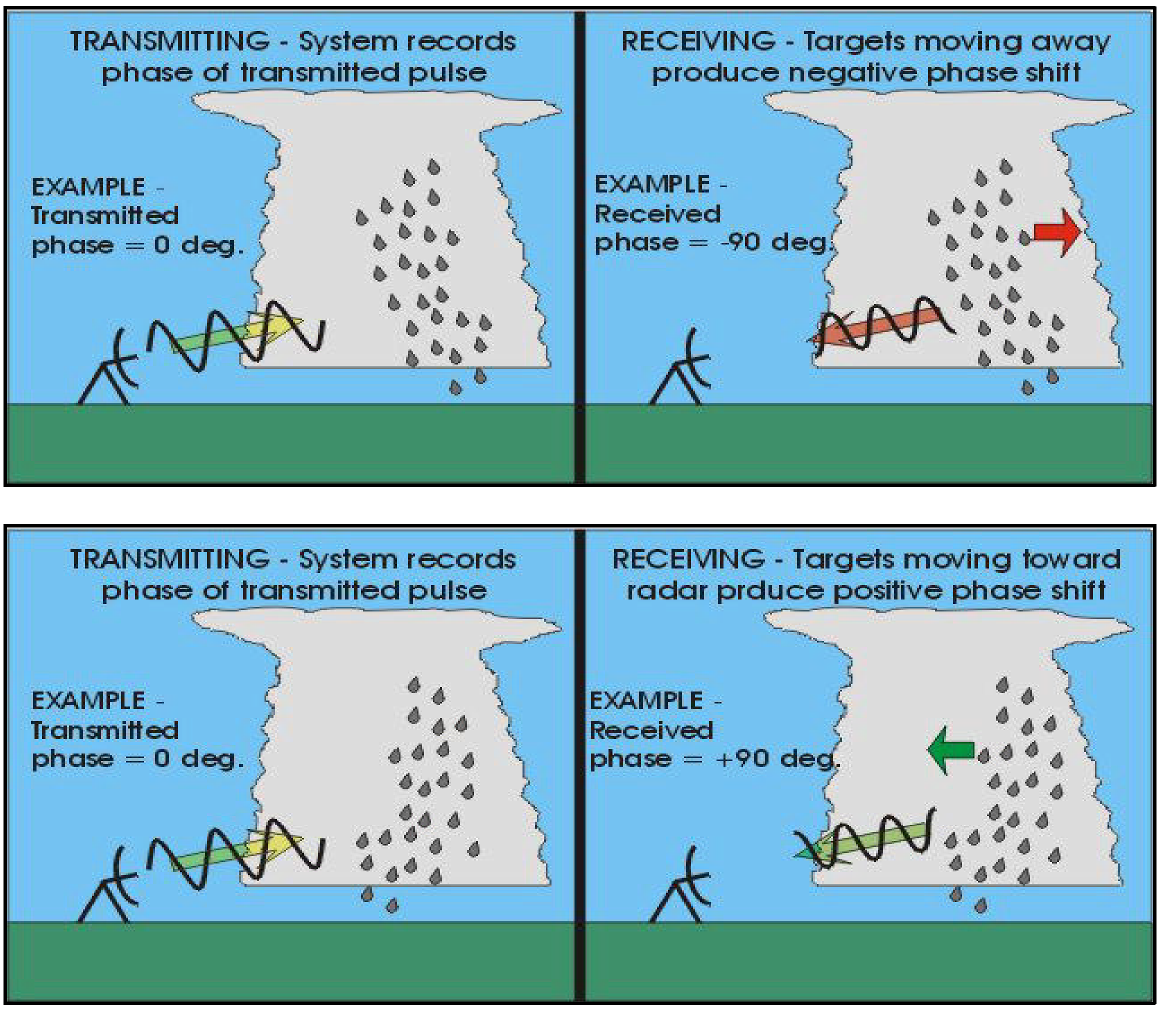

Figure 13-3: Method of Doppler velocity estimation. Outbound targets (moving away from radar) produce negative phase shift. Inbound targets produce positive phase shift

The effect is quite similar to the **"Doppler shift"** observed with sound waves. A body emitting sound waves will appear to transmit those waves in a higher frequency when it is approaching a location (inbound velocity = positive shift). As the body moves away from a location, the sound waves will have a lower frequency (outbound velocity = negative shift). You have probably been outside at some time when an emergency vehicle drove past you with its siren blaring. As the vehicle passed your location, the pitch of the siren lowered.

Radial velocity, however, will probably not equal the actual velocity of the target. If the actual motion is directly toward or away from the radar, then the radial velocity will indeed equal the actual velocity. If the target's motion is perpendicular to the radar beam, then the radial velocity display will be zero. If the target is moving at an angle to the beam, then the radial velocity will be some fraction of the actual speed. See Figure 13-4 below for a comparison of radial and actual velocity.

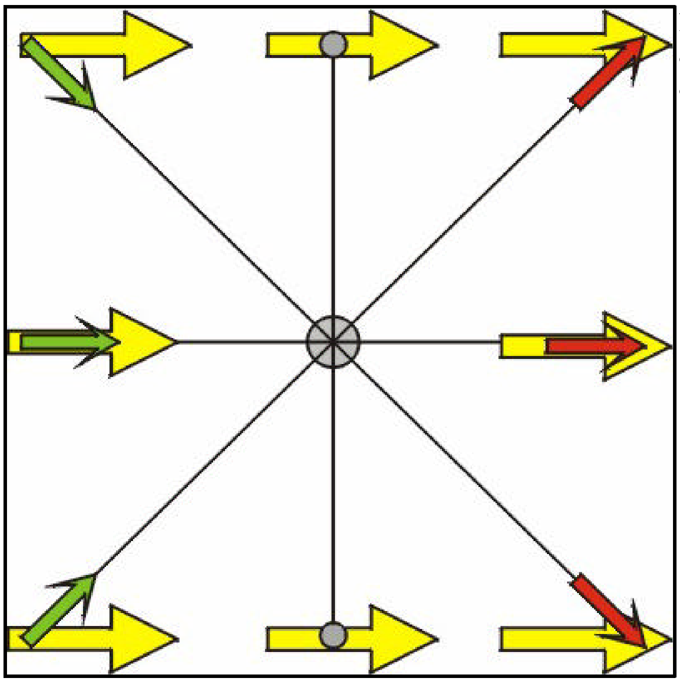

Figure 13-5: Comparison of actual velocity (white arrows) with Doppler velocity estimates (dark arrows) for various angles.

SCANNING STRAGEGIES AND PRODUCTS

Older weather radars required an operator to manually tilt the antenna up and down whenever a vertical cross section of a storm was desired, or when the upper parts of a storm needed to be investigated. The WSR-88D employs **scanning strategies** in which the antenna automatically raises to higher and higher angles as it turns. These automatic elevation sequences are called **volume scans**. In precipitation mode, the WSR-88D completes a volume scan every 5-6 minutes, providing an updated 3-dimensional look at the atmosphere around the radar site.

With older weather radars, which usually operated at a single elevation angle, the picture on the radar system's screen was continuously updated as the antenna turned. With the WSR-88D's scanning strategies this is not possible. Instead, as the volume scan progresses, the WSR-88D's computer system compiles the radar data and generates specific images from the volume scan for display on the system's monitors. These images are called **products**.

BASIC RADAR PRODUCTS

As indicated earlier, the weather radar system sends out a short pulse of radio waves, then "listens" for a portion of the pulse to be reflected back to the antenna. As the size and/or number of targets (raindrops, hailstones, etc.) intersected by the pulse increases, the strength of the radar echo increases. The returned power from targets is displayed on the WSR-88D as a product called **reflectivity**. The reflectivity display is typically shown on television weathercasts. By keeping track of the phase of the transmitted pulse, then comparing it with the returned echo's phase, motion of the targets toward or away from the radar can also be determined. This information is contained in the **velocity** product.

Figure 13-5 (below left) is an example of a reflectivity display. Reflectivity values are displayed in units called dBZ (decibels with respect to reflectivity Z, for you technical types). The color scale for the display is shown on the right hand side of the display along with other important information (time of the volume scan, resolution of the product, antenna elevation angle, maximum reflectivity value). On the display, cool colors represent lower reflectivity values associated with large cloud droplets and light to moderate rain. Warm colors represent higher reflectivities which suggest moderate to heavy rain and hail.

Figure 13-6 below right is an example of a velocity display. The radial velocity speeds are shown in **knots** (1 knot = 1.14 miles an hour). The display is set up similar to the reflectivity display, with the color scale and information regarding the velocity product on the right hand side of the screen. Shades of red indicate outbound motion or positive velocities (away from the radar) while green shades depict motion toward the radar (negative velocities). The brighter the shade, the higher the velocity. Module 14 will show some color examples of reflectivity and velocity plots.

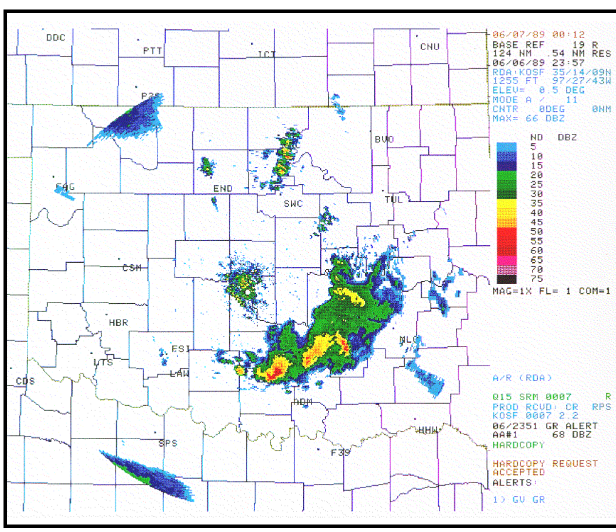

Figure 13-5: WSR-88D Reflectivity product

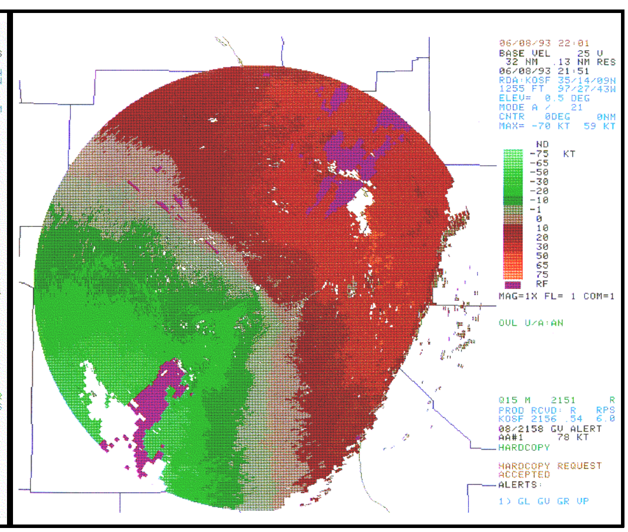

Figure 13-6: WSR-88D Velocity product